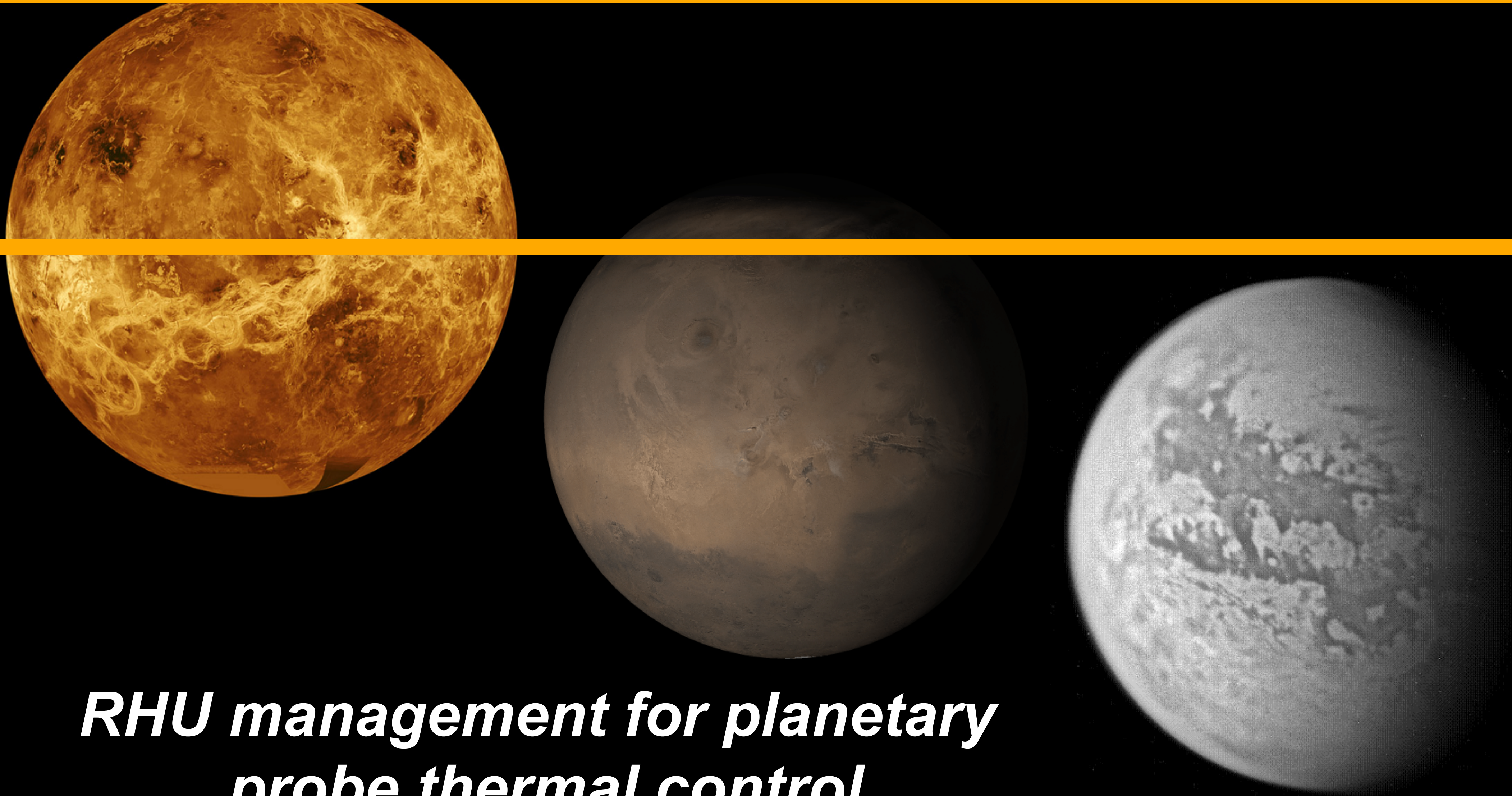


RHU management for planetary probe thermal control

D. Lebleu

Content

> RHU ?

> Advantages and drawbacks

> ALCATEL ALENIA SPACE experiences on probe missions
- HUYGENS - Mission to Titan
- NETLANDER - Geophysical station on Mars
- EXOMARS - A European rover on Mars

> Some conclusions and recommendations

RHU ?

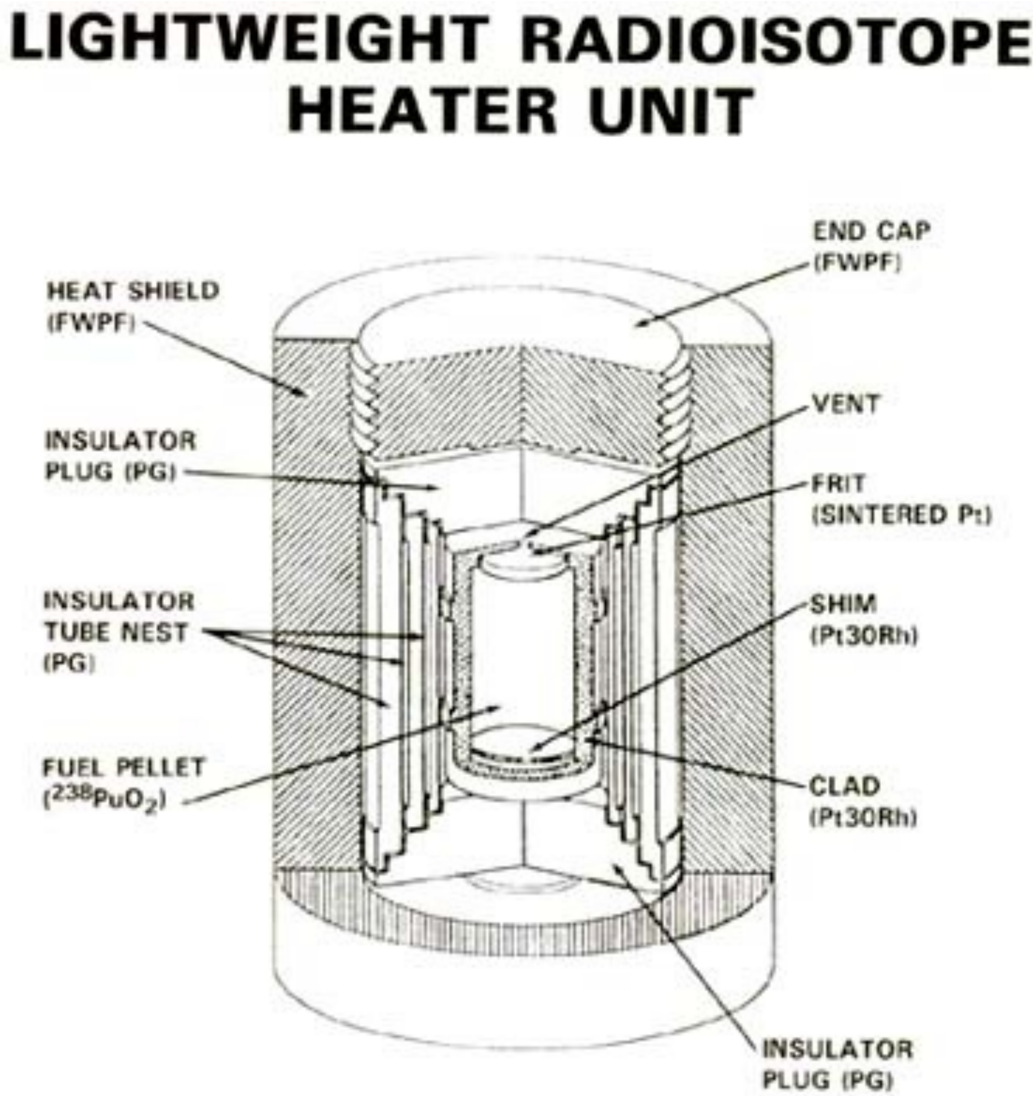
> RHU = Radiositope Heater Unit

- Electrical heaters are classically used for spacecraft heating in cold cases, and the required electrical power can be provided by either:
  - Solar array
  - Batteries
  - RTG (Radiositope Thermoelectric Generator)
- When solar flux is reduced, or when mass limitation constraints the system, It could be necessary to implement an alternate heating power system
  - Autonomous
  - Without constraints on the system

How does it work ?

> Principle

- A pellet of natural radioactive element is encapsulate within a shell
- The pellet is calibrated to provide the requested heat dissipation,which is spread through the environment by the external shell
- Typical design :
  - 1W heat dissipation
  - 3cm x 3cm
  - 40 g
  - Pellet material: Plutonium (3 g)
- The nature of the radioactive material lead to design the shell for most critical events: Atmospheric reentry, high velocity impact, fire, …



Courtesy US department of Energy

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Advantages for thermal control and system

- Provide heating power without any impact on the Electrical power supply
    - No solar cells area
    - No battery
    - No wiring
    - No validation (on ground electrical testing)
  - In addition, the mass efficiency wrt electrically powered system is similar
  - RHU are very reliable, without moving parts and very robust to the external environment

- They are extensively used for deep space mission, when the solar flux decay lead to unacceptable solar array size (Pioneer, Voyager, Galileo, Cassini) and when solar array is not necessarily appropriate to the mission (Apollo)

- RHU were developed in parallel by both USA and Russia for deep space mission

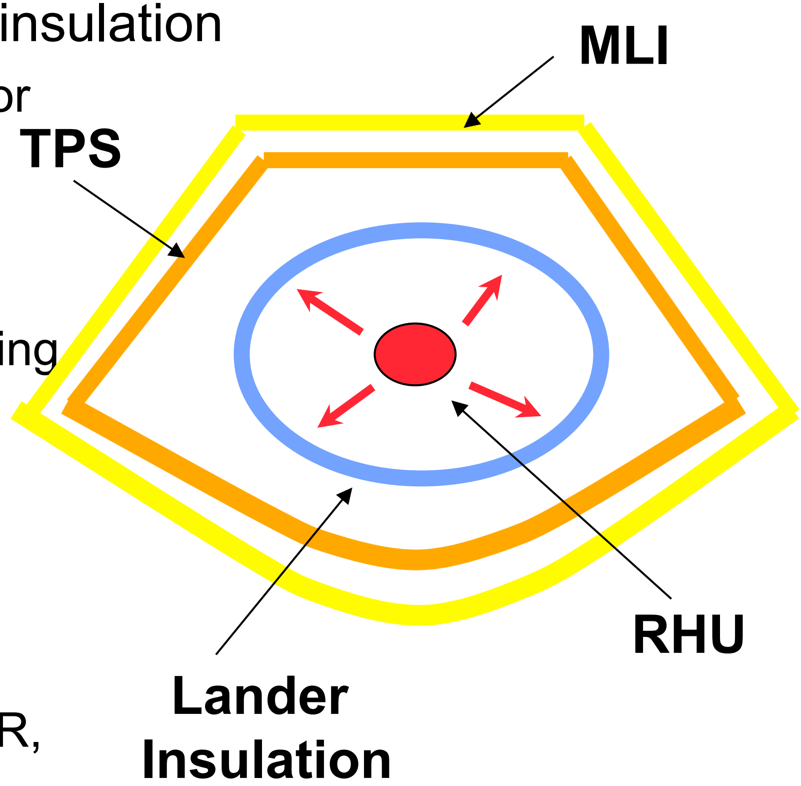
Drawbacks for thermal control and system (1/5)

- **It cannot be switched OFF !**
  - In flight Hot cases have to be strongly managed
    - Beginning of life could lead to specific thermal control design and features
  - On Ground activity necessitate particular management
    - Active cooling system ➔ Difficulty to be implemented wrt Reentry probe thermal protection efficiency (no holes in the TPS …)
    - Late implementation in probe Integration ➔ Design impact with late access door
      - Difficult to manage for Reentry probe: Thermal protection system efficiency
      - Planetary protection aspects (see after)
  - On Launcher activities prior Launch
    - Active cooling system is difficult to implement ➔ Launcher modification
    - Need of proper management between fairing late access door closing and effective launch (see after)
- Power decay with mission duration
    - Higher dissipation in beginning of life, in hot case closed to the Sun
    - Lower dissipation in cold case far from the Sun

Drawbacks for thermal control and system (2/5)

> On ground active cooling system

- An entry probe with RHU is a pressure cooker from thermal point of view !
- An entry probe is surrounded by several layers of insulation
  - > Descent module/surface module proper insulation for its operation
    - – Huygens insulation to withstand the 100K atmosphere temperature on Titan
    - – MER rover insulation to withstand the 180K during night on Mars
  - > Thermal protection system, necessary for the entry phase
  - > MLI, to avoid freezing during the several years of cruise
  - > Potentially, air bags around the landing vehicle (MER, NETLANDER)



- On ground, without cold shroud as space, the temperature is over 100°C in few days

➔ It is mandatory to implement a cold shroud for the probe

Drawbacks for thermal control and system (3/5)

- RHU implementation late in the assembly process
  - In order to simplify the AIT activities, the major part of the process is followed without the RHU
    - Avoid management of constant thermal dissipation within the vehicle
    - Availability of fully operating RHU just before the beginning of the mission, e.g. “nominal dissipation”
    - Radiologic protection for the personnel
  - RHU are implemented at the end of the Integration phase, often on the launcher authority clean room
  - Design impact
    - Possibility to open the probe
    - Availability of a late access door

➔ Significant integration activities **after** all verification and validation tests

Drawbacks for thermal control and system (4/5)

- Remind on Planetary protection
  - COSPAR has established regulation with regard to biological cleanliness of any element which will land on an other solar system body, which depends on:
    - The probability of occurrence of life actually
    - The potential life emerging in the body ancient ages
    - The ability of life carried from Earth with the vehicle to evolve on the landing area
  - Typical level for Mars mission is 300 spores/m²
  - Impacts for the spacecraft
    - This induces to use sterilisation procedures (dry heat, gamma rays, …) adapted to each elements as a unique method is not applicable to all elements
      - Electronics does not withstand 110°C dry heat for days
      - Composite structure, parachute or TPS does not withstand gamma rays
    - Need to perform the S/C Integration within a class 100 clean room especially adapted to biological cleanliness (surgery like).
- Such caution during the vehicle integration are difficultly compatible with probe opening on launcher authority “clean” room

Drawbacks for thermal control and system (5/5)

> Pre-Launch - On launcher, before the flight

- The spacecraft is implemented within the fairing days before the launch
  - The active cooling system has still to be available at this phase
- The composite spacecraft+fairing is thus placed on the launcher
- … and the fairing has to be closed !

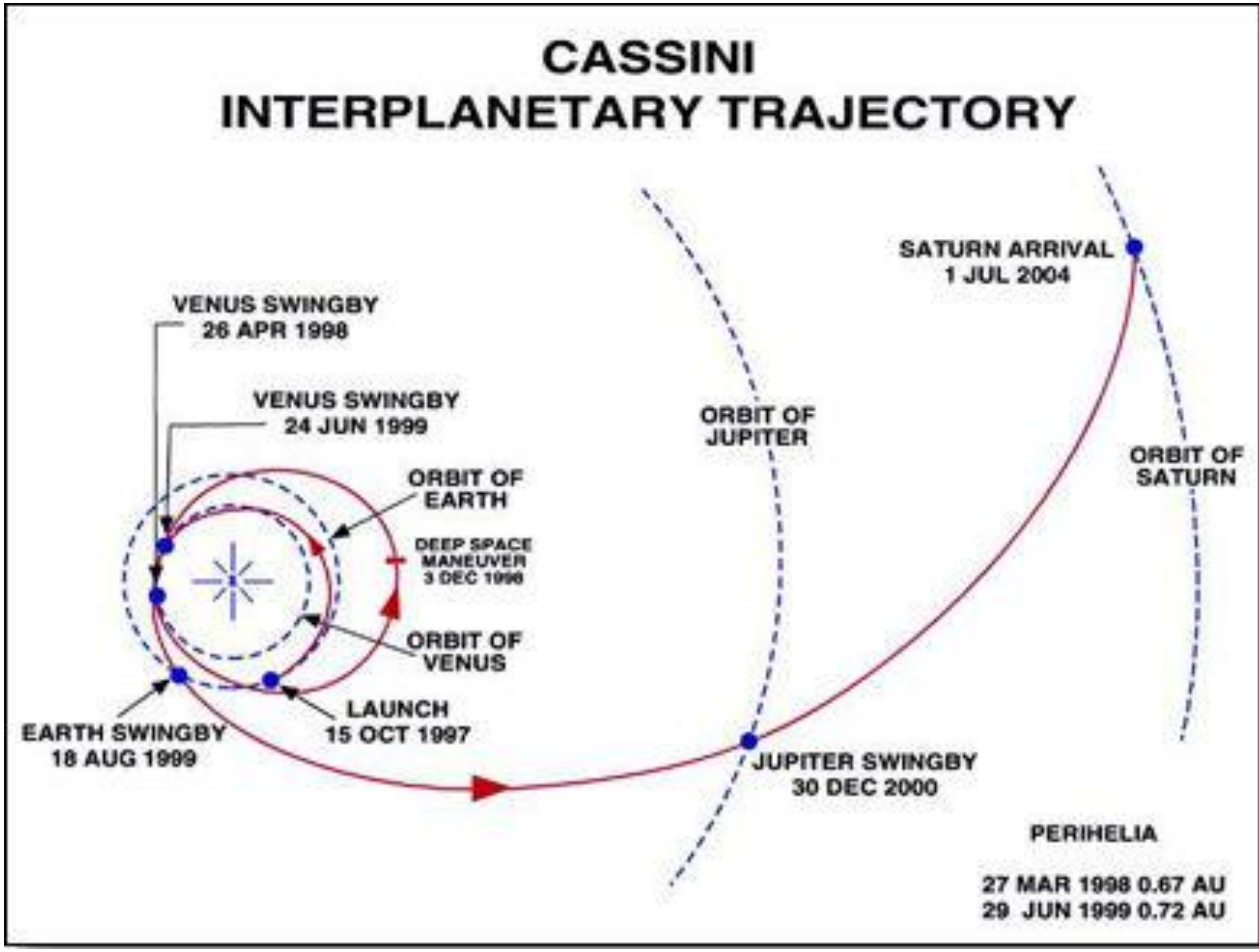
- Depending on the launcher sequence, the duration between the fairing closure and the launch is different, from few hours up to almost a day
  - During this phase, the probe cannot be cooled and only thermal inertia can avoid overheating

➔ RHU implementation and probe and spacecraft design, related to the mission, impose constraints on the launcher

➔ Maximum duration constraints for pre-launch sequence

In situ TITAN science - HUYGENS Probe

- HUYGENS mission life
  - Launch on Titan 4
  - 7 years of Cruise
    - Solar constant from 2700W/m² (Venus flyby) to 15W/m² (around Saturn)
  - 22 days of coast after separation from CASSINI
  - 2 minutes of aerothermal flux
  - 1.5 hours within Titan atmosphere (about 100K)
  - More than 3 hours on Titan ground (about 90K)



Courtesy NASA / JPL

In situ TITAN science - HUYGENS Probe

> Why using RHU

- After separation from CASSINI, HUYGENS is entirely exposed to deep space
- The solar flux is not sufficient to provide enough thermal energy to maintain a temperature level compatible with the mission
- 22 days of coast phase is too long to consider thermal inertia or batteries as a solution

→ Mass efficiency was favourable to RHU solution compared to PCM or other design, which in addition will required heating power from CASSINI during the 7 years Cruise phase

- 35 RHU's were implemented
  - > 35.6W to 33.7W along the mission

In situ TITAN science - HUYGENS Probe

> Impacts

- Implementation of a radiative window on the Frontshield for beginning of life
  - Area without MLI
  - Aluminium plate white painted
- Active cooling system on Ground inside the probe via probe late access door
- Active cooling system on launcher on the radiative window via the launcher late access door up to 4 hours before the launch (Launcher under tower)
- Limitation to about 10 hours of pre-launch activities, before necessity to recover the active cooling system on the radiative window

> Mission data

- Flight temperature about 5°C below the predictions in cruise hot case
  - Good agreement considering the fully passive thermal concept

    ➔ 80% of the RHU's power leaves the probe via MLI
- The probe was at 20°C on Titan surface before the loss of the link with CASSINI

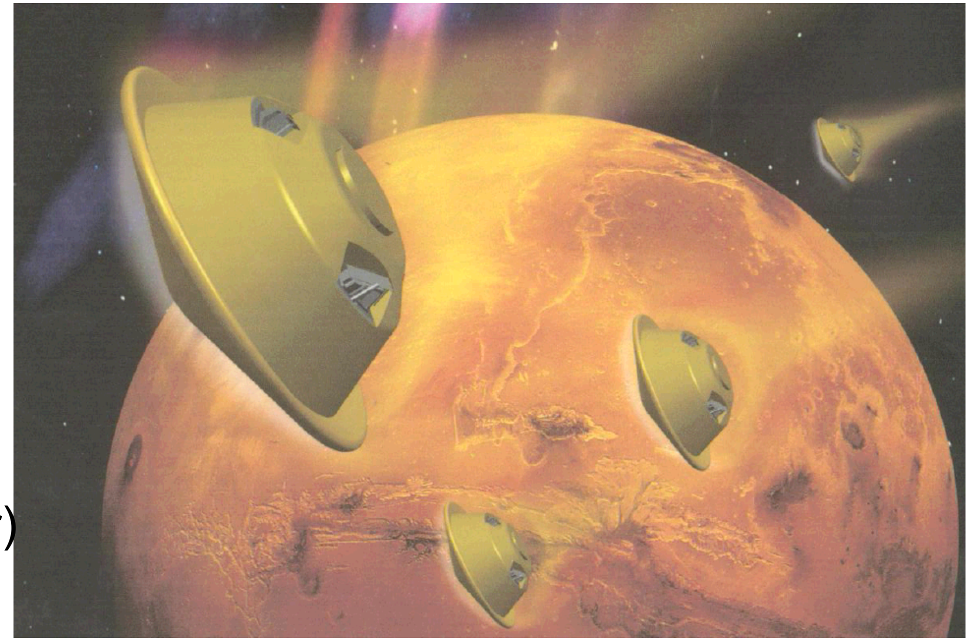
Mars on ground station – NETLANDER probe

> NETLANDER mission

- CNES mission in the frame of the Mars Sample Return CNES-NASA co-operative mission
- Network of 4 geophysical stations on the Mars surface
- Life time : 2 years on the surface (1 Mars year)
- Mission cancelled, following MSR cancellation, after successful EDLS phase B

> NETLANDER mission life

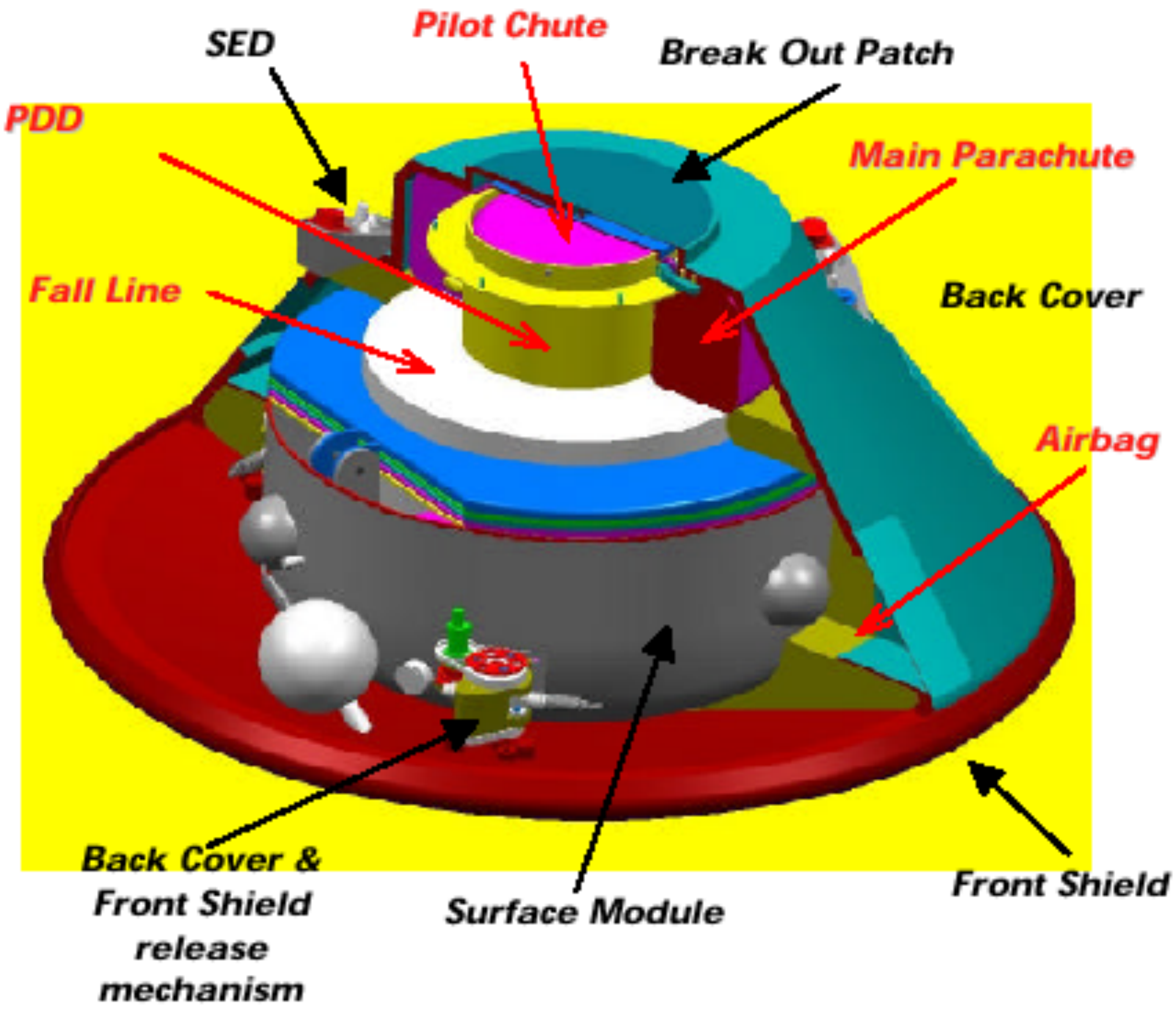
- Launch on ARIANE5 from Kourou
- 1 year of Cruise phase
- up to 28 days of Coast phase
- 2 minutes of aerothermal flux
- 2 Earth years on Mars surface
  - Full operation (science, relay data to Orbiter)
  - Including cold winter
  - Including low solar flux on Solar array during winter



Mars on ground station – NETLANDER probe

> NETLANDER concept

- Surface module
  - > The module which will operate on Mars surface
- EDLS
  - > All the elements necessary to manage a safe deposit of the surface module on Mars, from the Earth surface



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Mars on ground station – NETLANDER probe

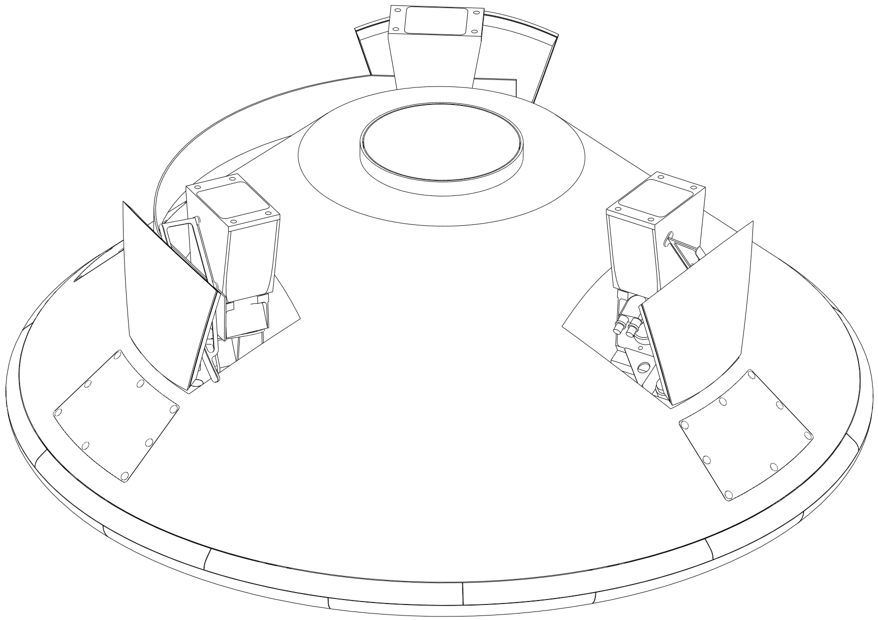
- Why using RHU ?
  - Solar array reasonable surface during winter does not allow both
    - full operation
    - and thermal heating system
  - RHU was foreseen to withstand the cold winter night without impact on daylight operation
    - RHU implemented in a joint module with the battery, for late integration
- Mission design constraints
  - The module for surface operation benefits of several layers of insulation when implemented on the launcher
    - Surface module proper insulation for energy saving on Mars
    - Airbag stowed around the module
    - TPS on the aeroshell
    - MLI around the external shape

➔ Necessary to extract the RHU exceeding power outside of the Surface Module

Mars on ground station – NETLANDER probe

> Impacts (1/2)

- Implementation of a Loop Heat Pipe to transfer the RHU power outside from the surface module
  - > Used during the mission on Mars surface
    - – Heat rejection modulation wrt external environment
      - > Day / night
      - > Summer / Winter
  - > Used while implemented into the EDLS to avoid overheating
- Implementation of a thermal path within the EDLS between the Surface Module interface
  - > Good thermal link between the surface module and the EDLS external side
    - – But which need not to be sensitive to entry aerothermal flux
  - > Implementation of a large radiator on the Probe/Vessel interface mechanism



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Mars on ground station – NETLANDER probe

Impacts (2/2)

- Implementation of a late access door through the EDLS
  - Planetary protection specific management
- Necessity of an active ventilation during AIT phase and since the spacecraft is implemented within the fairing
- Modification on Launcher for direct probe air cooling was proposed
  - Duration between launcher mating and launcher transfer to launch pad is nominally 7 days, potentially increased in case of aborted launch

Mars Rover - EXOMARS

> EXOMARS mission
- Search life or evidence of past life on Mars down to 2 meter below the surface
- Mobility ➔ A Rover on Mars (about the size of MER)

> Mission objective impact for the EXOMARS design
- High level of planetary protection requirement
  - Extreme stringent constraints on AIT, launch operation and flight

> EXOMARS mission life
- Launch on SOYUZ from Kourou
- 2 Years of Cruise
- 2 minutes of aerothermal flux
- 6 month of operation on Mars surface

- Actually in phase B1 - Definition of the major system concepts

Mars Rover - EXOMARS

> Why considering RHU for the EXOMARS rover ?

- EXOMARS Rover is Solar powered
  - > Objectives to reduce power consumption
    - – Reduce at the minimum the thermal heating during night
  - > Power management
    - – During day, operation and battery charging
    - – During the night, using the battery power to compensate the heat leaks

- Using RHU could allow:
  - > to reduce the battery size and mass
  - > hence to reduce the solar array size

➔ Optimise system with maximum power to the payload

Mars Rover - EXOMARS

- Potential impacts (1/3)
  - Planetary protection – Solution 1: RHU late integration is considered
    - extreme stringent cautions have to be considered for the integration team,
    - and dedicated efficient MGSE have to be developed in order to guaranty the payload sterile environment

    - In case of unexpected break of the biological protection during this phase
      - The impact on planning could be extremely important
        - Dis-mounting of the Rover from the EDLS
        - Dis-mounting of the payload from the rover
        - Payload sterilisation and Rover + EDLS biological cleaning
        - Second integration and potential new sequence of system tests
        - Second late RHU integration attempt
      - The launch windows for Mars missions are almost every 2 years
        - The risk is high to loss the launch window
        - or to consider large margins on the planning

→ Risk at management / schedule level

Mars Rover - EXOMARS

> Potential impacts (2/3)

- Planetary protection – Solution 2: RHU integration along nominal AIT activities
  - Management of radioisotopic elements during months (years?) in AIT clean room and test facilities
    - Radioprotection management for the staff ==> Definitely unusual
    - Security wrt robbery, malicious intent, terrorism
    - Thermal aspect (extraction of the RHU energy during the integration and tests sequence

➔ Dedicated Clean Room/building for EXOMARS ?

Mars Rover - EXOMARS

> Potential impacts (3/3)

- Need to extract the RHU dissipation from the Rover since RHU integration within the Rover
  - An extraction device (Fluid loop) have to be considered to manage the temperature level of the Rover and EDLS elements during flight phases, and on earth ground phases

➔ A thermal design avoiding the use of RHUs for EXOMARS shall be thoroughly considered

  - This shall be traded off taking into account not only Rover mission aspects but also the complete system life cycle including ground testing phases

Some conclusions

- For some missions, RHU is mandatory
  - Deep space mission with a very low solar flux large decrease eliminate electrically powered heating system
- RHU has strong impacts on the program, technical impact and management impact
  - Design impact have to be considered early in the development
  - Integration and tests constraints have to prepared
  - Launcher constraints have not to be forgotten
- Necessity of RHU shall be technically demonstrated at system level

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